A Cosmologic Model Based on the Equivalence of Expansion and Light Retardation
Part 1: Large-Scale Aspects

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February 7, 2008

Abstract

Proceeding from a homogeneous and isotropic Friedmann universe a conceptional problem concerning light propagation in an expanding universe is brought up. As a possible solution of this problem it is suggested that light waves do not scale with $R(t)$. With the aid of a Generalized Equivalence Principle a cosmologic model with variable "constants" c, H, and G is constructed. It is shown that with an appropriate variation of the Boltzmann "constant" k the thermal evolution of the universe is similar to the standard model. It is further shown that this model explains the cosmological redshift as well as certain problems of the standard model (horizon, flatness, accelerated expansion of the universe).

PACS numbers: 98.80.Bp, 98.80.Hw, 04.20.Cv.
Keywords: cosmology, velocity of light, expansion

1 Introduction

There is no doubt that the standard model of cosmology is the most successful approach in describing the universe as a whole while accounting for numerous empirical data provided by macro- and microphysical observations. Yet, the standard model causes some complications, such as an initial singularity, a flatness, horizon and density fluctuation problem, and some more. Although some of them could be avoided by re-introducing the cosmological constant Λ, which grants a variety of models like inflationary, extended or hyperextended expansion, the original simplicity and beauty of the model has disappeared. In this paper it will be attempted to show that with the aid of a simple yet physically productive principle of the same category as the Equivalence or the Cosmological Principle it is possible to obtain an elementary description of the universe while avoiding the disadvantages of the standard model. The validity of the Cosmological Principle is assumed. Thus the scope is limited to Friedmann-Robertson-Lemaître-universes, which are based on the principles of spatial isotropy and homogeneity of the universe.

2 A Problem of Light Propagation in Friedmann universes

Among the various problems of the standard Friedmann universe there is one which had been mentioned occasionally in the past but which had not been paid full attention so far. It concerns the dependence of the dielectric and magnetic constants ε_0 and μ on the gravitational potential Φ. The Maxwell equations in a constant gravitational field imply the relation

$$\varepsilon = \mu = (1 + 2\Phi/c^2)^{-1/2} \tag{1}$$

(Møller [1969,1972], Landau/Lifshitz [1962,1975]). In cosmology one is interested in large scale *eigen* gravitation of the universe rather than in local gravitational fields. It arises the question, in how far a universal Φ could vary. In Newtonian terms, the potential Φ_E of the proper gravitation of the universe can be written as

$$\Phi_E = -M_u G/R \tag{2}$$

where M_u ist the universal mass, G the gravitational constant and R the extension (radius) of the universe. In Friedmann models, R is increasing as a function of time. This leads to a decreasing $\Phi_E(t)$, if one does not postulate *ad hoc* assumptions between M_u, G and R to keep the expression constant. According to eq. (1) we then obtain time-dependent "constants" $\varepsilon(t)$ and $\mu(t)$ with increasing values. (A detailed mathematical analysis on the variation of vacuum permittivity in Friedmann universes was given by Sumner [1994].) Because $(\varepsilon\mu)^{-1/2} = c$ the velocity of light should also decrease. We should become familiar with the idea, that a variable c is not a heresy. Even Einstein (1911) was ready to give up the absolute constancy of light according to Special Relativity when he worked on the influence of gravitation on light propagation. In this paper he developed following equation which shows the velocity of light as a function of the gravitational potential $c = c_0(1 + \Phi/c^2)$. Years later he discovered, that it is more comfortable to keep c constant and to interprete the elapsed time as a function of Φ. This led to the present form of General Relativity. However, Φ in Einstein's equation was restricted to local gravitational fields, which were regarded constant. Different values of Φ result in different lapses of time. Friedmann's solutions of the gravitaional equations in accordance with Hubble's observations of cosmological red shifts imply, as we have seen, a variable $\Phi_E(t)$. This is a completely different situation. Just like Einstein in the 1910's we have the choice to interprete a globally decreasing Φ_E either as a global decrease of the speed of light or in the sense of varying universal time. Both alternatives, which base on mathematical (i.e. "absolute") scales, should be equivalent. However, the mere idea that reference scales could vary causes us to avoid the concept of absolute units and to rely on physical scales as it is practically done by defining space and time by electromagnetic (i.e. physical) processes. That means in particular that reference scales are not defined seperately but in relation to each other. The following equation (next section, eq.[3]) can be understood in this sense.

3 A New Mechanism of Light Propagation and its Relation to an Expanding Universe

We define a relative decrease of the velocity of light with reference to an expanding universe. This implies the following mechanism of light propagation. Let there be a source E emitting with a (mathematically) constant frequency ν. Since c decreases continuously, the wave-length λ decreases proportionally to c at emission. While traveling through the universe, however, λ shall remain constant. Namely, it shall not expand with $R(t)$ as in the standard model. The assumption of constant c and non-expanding light waves over cosmic distances means a retarded arrival of light in an expanding universe. To illustrate that point: Let the distance between an emission source E and an observer O at time t_0 be $m\lambda$ of a defined wave-length. At time $t_1 > t_0$ the distance EO has expanded with $R(t)$, however, not the single λ_r. Therefore the distance at t_1 in terms of the light wave will be $n\lambda_r$ (with $n > m$). The runtime of a light beam with constant speed starting at t_1 will be longer than light that left E at t_0. This problem casts a new light on the relation of expansion and the constancy of light: In the standard model a huge ominous force is needed to maintain expansion against gravity (vacuum energy, cosmological constant and quintessence are synonyms of possible explanations). What, if the nature of universal expansion were that in terms of decreasing wave-lengths λ at emission? Then there would be no more necessity for a repulsive force, which maintains expansion. Usually length is defined by an invariable rigid rod. This is, however, a mathematical definition, because *in praxi* on has to utilize a physical reference scale like defined wave-lengths. There is no way for us to find out whether the universe is "really" expanding or whether the speed of light is "really" decreasing. Both phenomena are conditioning each other. This new principle of the equivalence of space expansion and light retardation can be formulated

$$Rc = const. \tag{3}$$

where c is the seemingly retarded velocity of light in an expanding universe and R is from now on regarded as the variable radius of the universe in the unit of meter (whereas the scale factor a is dimensionless).
As the term "equivalence principle" is applied to inert and heavy masses, the meaning of eq.(3) will be referred to as "Indiscernibility Principle" (IP).

It has to be mentioned that the IP is not an additional assumption; it just replaces $c = const.$ of standard cosmology. (By the way: This concept avoids the paradox situation of a light beam from a distant region of the universe entering a galaxy cluster: Its waves should suddenly cease expansion and carry on with it when leaving the cluster.)
To demonstrate the mathematical aspects of the IR (eq.3) we regard light propagation in Robertson-Walker-Metrics (RWM). Because of homogeneity and isotropy of space we can regard a light trajectory with $\chi(t), \theta = const., \phi = const.$ which reaches from $\chi(t_1) = 0$ to $\chi(t_0) = \chi$. Then the RWM reduces to

$$ds^2 = c^2 dt^2 - R(t)^2 d\chi^2 = 0 \iff d\chi = cdt/R(t) \tag{4}$$

We now regard two subsequent wave peaks. Both have to travel the same distance from the source to the receiver (from 0 to χ):

$$\chi = \int_{t_1}^{t_0} \frac{c(t)dt}{R(t)} = \int_{t_1+\delta t_1}^{t_0+\delta t_0} \frac{c(t)dt}{R(t)} \tag{5}$$

The spatial distance of the two subsequent wave peaks is $\lambda = c/\nu$. The temporal distance δt relates to the frequency ν via

$$\delta t = 1/\nu \tag{6}$$

From eq.(5) follows

$$0 = \int_{t_0}^{t_0+\delta t_0} \frac{c(t)dt}{R(t)} - \int_{t_1}^{t_1+\delta t_1} \frac{c(t)dt}{R(t)} = \frac{c(t_0)\delta t_0}{R(t_0)} - \frac{c(t_1)\delta t_1}{R(t_1)} \tag{7}$$

(Because $\delta \ll \chi$ we can regard $R(t)$ in the integration interval as constant.) From (6) and (7) we have for the emitted frequency ν_1 and the received frequency ν_0

$$R(t_0)\nu_0 c(t_1) = R(t_1)\nu_1 c(t_0) \tag{8}$$

The standard model assumes $c = const.$ in (7) and (8) and concludes $R\nu = const.$ We see, however, that "stretching" waves are in general not an implication of the RWM but rather of the assumption of a constant c.
While in the standard model expansion and light propagation can be imagined within the szenario of an expanding balloon, the suggested mechanism

of light propagation corresponds to the conveyor belt mechanism where a pen swinging rectangular to the belt's movement, drawing waves upon it. The product of the pen's frequency and the wave-length gives the speed of the belt identified with c. A diminishing speed of the belt reduces the wave-lengths at emission or the other way round: reduced wave-lengths caused by the expansion discrepancy of R and λ at constant swinging frequency diminishes the product c. The particle version is similar: A photon is placed with constant frequency on the decelerating belt.
This Retarded Light Model will in the following serve to treat the cosmological questions. (Of course the balloon picture can be further maintained if one is aware that in this model space expansion results in the fact that the coordinate system does not co-expand.)

4 Determination of Time Variabilities of Cosmological Quantities H, c and R

According to the Indiscernibility Principle (IP) it makes no sense to propagate either a "real" expanding universe or a "real" decreasing speed of light. The mathematical treatment combines both properties: Eq.(3) can be written $\dot{R}/R = -\dot{c}/c$. With the use of $\dot{R}/R = H$, where H represents the Hubble parameter (rather than Hubble constant) we obtain the expression

$$\frac{\dot{R}}{R} = H = -\frac{\dot{c}}{c} \tag{9}$$

We can write R as a function of $c(t)$ and $H(t)$: $R = c/H$ and obtain

$$Rc = c^2/H = const. \tag{10}$$

(In the following time-dependent quantities like $R(t)$, $c(t)$ are abbreviated R, c, and so on. Certain value are characterized by indices like R_0.)
From (10) the time dependence of H can be calculated:

$$\frac{d}{dt}\left(\frac{c^2}{H}\right) = 0 \tag{11}$$

and resolved to $\dot{H}$:

$$\dot{H} = -2H^2 \tag{12}$$

In regard of (9) and (12) the propagation of the universe is

$$\dot{R} = c \tag{13}$$

This was formerly deduced by Milne (1948) in the frame of his Kinematic Relativity. Differentiation of (13) gives according to (9)

$$\ddot{R} = \dot{c} = -Hc \tag{14}$$

From (12) we can derive $H(t)$ by seperating of variables and integration:

$$H(t) = \frac{1}{1/H_0 + 2t} = \frac{H_0}{1 + 2H_0 t} \tag{15}$$

From (14) and (15) the temporal variation of c (in an expanding universe) is

$$c(t) = \frac{c_0}{\sqrt{1 + 2H_0 t}} \tag{16}$$

Now we can specify the expansion of the universe. Its radius R has a time dependence of

$$R(t) = \frac{c(t)}{H(t)} = \frac{c_0}{H_0}\sqrt{1 + 2H_0 t} = R_0\sqrt{1 + 2H_0 t} \tag{17}$$

5 Cosmological Redshift in the Retarded Light Model

Standard cosmology explains the cosmological redshift by expansion of λ while the light beam travels a distance r. In the Retarded Light Model (RLM) a certain wave-length remains, once emitted, unchanged. However, λ is a function of time. The earlier it was emitted, the faster c and thus the larger λ had been. When we observe a spectral redshift, this is because the wave was emitted much earlier in the history of the universe compared to the same electromagnetic process observed at present on our planet. In the following a simple deduction, based on conventional terms, is given.
Hubble's law, as it is commonly referred to, is

$$v = Hr \tag{18}$$

Since the transmission speed of photons is finite we can express any distance r by the runtime of light.

$$r = ct \tag{19}$$

(Note that in standard cosmology c is constant while in the RLM it is a function of time here. As it is calculated with functions and not with certain values, the expressions can be left unintegrated at the present state.)
Eqs. (19) and (18) give

$$v = Hct \tag{20}$$

Applying (20) to the expanding universe, v means the receding velocity of cosmic objects and t the time their light has taken to reach us. Division by t gives the mean acceleration $\bar{a}$ of cosmic objects in dependence of their distance (standard interpretation) or, according to the RLM equivalence principle eq. (3), the deceleration of c:

$$-v/t = -\bar{a} = \dot{c} = -Hc \tag{21}$$

Note that (21) is deduced from standard terms only, while the identical result in (14) uses a new concept of expansion based on the IP.
In the standard model one can describe the cosmological redshift in a first order approximation as a Doppler effect. This is also possible within the RLM, as first shown in Huber (1992). In the following we use the particle picture of the conveyor belt model: We regard photons which are emitted by a radiation source with a constant frequency T_0^{-1} but with decreasing velocity of light. The frequency of radiation shall be the same everywhere in the universe and at all times. This condition guarantees the spatial and temporal invariance of physical (or chemical) processes and is just another formulation for the Cosmological Principle stating the homogeneity of the universe. The initial speed of the photon n shall be c_{0n}. The index n means that the initial speed c_0 decreases with time. We define a very first photon with the speed c_{00}. Then the varying initial speeds can be written

$$c_{0n} = c_{00} - anT_0 \tag{22}$$

where a is the (negative) acceleration. At time $t > nT_0$ the nth photon has the speed

$$c_n(t) = c_{0n} - a(t - nT_0) = c_{00} - at \tag{23}$$

At time t photon n has travelled a distance

$$r(t) = \int_{nT_0}^{t} c_n(t')dt' = c_{00}t - \frac{a}{2}t^2 - c_{00}nT_0 + \frac{a}{2}(nT_0)^2 \tag{24}$$

This equation can be resolved for the time $t_r^{(n)}$ at which photon n has travelled the distance r:

$$\begin{aligned} t_r^{(n)} &= \frac{1}{a}\left(c_{00} - \sqrt{c_{00}^2 + a^2(nT_0)^2 - 2ac_{00}nT_0 - 2ar}\right) \\ &= \frac{1}{a}\left(c_{00} - (c_{00} - anT_0)\sqrt{1 - \frac{2ar}{(c_{00} - anT_0)^2}}\right) \end{aligned} \tag{25}$$

where the positive root is excluded because one must have $t_r^{(n)} = nT_0$ for $r = 0$. The time interval $T_r^{(n)}$ between the arrival of two photons n and $n+1$ at the observer at distance r is

$$T_r^{(n)} = t_r^{(n+1)} - t_r^{(n)} \tag{26}$$

Inserting (25) in (26) we get

$$T_r^{(n)} = -\frac{1}{a}\left\{ \begin{array}{l} (c_{00} - a[n+1]T_0)\sqrt{1 - \frac{2ar}{(c_{00}-a[n+1]T_0)^2}} \\ -(c_{00} - anT_0)\sqrt{1 - \frac{2ar}{(c_{00}-anT_0)^2}} \end{array} \right\} \tag{27}$$

This time-distance-relation gives the absorbtion interval T in dependence on the distance r from the radiation source and the (absolute) time nT_0.
To obtain a Doppler interpretation we restrict (27) to relatively small distances r. (We know from standard cosmology, that the Doppler interpretation of the cosmological redshift is only valid for distances $r < 0.5R_0$.) Then we can expand (27) in powers of $\frac{2ar}{(c_{00}-anT_0)^2} \ll 1$:

$$T_r^{(n)} \approx -\frac{1}{a}\left\{-aT_0 - ar\left(\frac{aT_0}{c_{00}^2\left[1 - \frac{a(2n+1)T_0}{c_{00}} + \frac{a^2n(n+1)T_0^2}{c_{00}^2}\right]}\right)\right\} \tag{28}$$

Under the additional assumption $c_{00} \gg anT_0$ this expansion leads to

$$T_r^{(n)} \approx T_0\left(1 + \frac{ar}{c_{00}^2}\right) \tag{29}$$

or written with frequency $\nu_r = T_r^{-1}$:

$$\nu_r \approx \frac{\nu_0}{1 + \frac{ar}{c_{00}^2}} \tag{30}$$

The classical Doppler effect for the frequency of light escaping from a source moving with velocity v is approximately given by

$$\nu = \frac{\nu_0}{1 + \frac{v}{c}} \tag{31}$$

Interpreting the Hubble flow as Doppler redshift we have to replace v by Hr and get:

$$\nu = \frac{\nu_0}{1 + \frac{Hr}{c}} \tag{32}$$

Comparing (32) with (30) we immediately find that both expressions are equal for $c_{00} = c$ and $ar/c = Hr$ or

$$a = Hc \tag{33}$$

This calculation shows that within the Retarded Light Model the cosmological redshift can be interpreted as a Doppler effect just like in the standard model. The acceleration parameter a has been introduced negatively in (22) so it bears no explicit sign. It can be associated with $-\dot{c}$. The result of (33) represents another independent determination of the results of (14) and (21). There is yet another method to obtain this result. In the RWM we have for the distance D between an emitter and an observer the following relation, restricted to the first two powers of a Taylor expansion:

$$D = D(t_0) = R(t_0)\chi \simeq c(t_0 - t_1) + \frac{Hc}{2}(t_0 - t_1)^2 \tag{34}$$

where χ is the light trajectory from a remote light source ($\chi = 0$) to the observer (χ). This expression is within its limits identical with the formula of accelerated movement $d = v_0 t + at^2/2$. Thus we can associate the acceleration a with Hc. Because the increase of distance corresponds to the decrease of c we have $a = -\dot{c} = Hc$. It seems that there is hardly a chance to get around the conclusion that the cosmological redshift is caused by a light deceleration of $\dot{c} = -Hc$. The last three of the four presented methods to determine $\dot{c}$ in order to compensate for the cosmological red shift do not make use of the IP, so this relation stated above can be regarded as a consequence of the new interpretation of the observed cosmological redshift.

6 Conclusions from Friedmann's equations

Varying constants c and g applied in General Relativity usually lead to Brans-Dicke theories. Even there the Friedmann solution holds under certain preconditions, as was shown by Albrecht/Magueijo and Barrow. The situation in the RLM is different, however. It deals with the fact that Friedmann's equations as a solution of Einstein's gravitational equations imply varying magnitudes like wave-lengths and distances in the universe, while there still exist non-varying scales (at least by definition). As a consequence of the Friedmann scale variation the RLM eliminates mathematically defined "absolute" scales and refers to physical processes only. So the RLM is not a super theory replacing or changing General Relativity; it is applicable within its Friedmann solution *only* and it wouldn't make sense elsewhere. The RLM is restricted to cosmological applications, where the universe as a whole and its *eigen* gravitation play a role. The description of local gravitational effects (star or galaxy interactions, for example) must follow the unaltered Einstein laws. Once one is aware of the hierarchy General Relativity – Friedmann solution – RLM, it is obvious that the Friedmann equations can be applied unaltered. There is just one exception: the cosmological constant Λ, which mediates in the standard model between gravitation and expansion, is superfluous, since the RLM itself is the theory of mediation. Friedmann's equations without Λ are:

$$\left(\frac{\dot{R}}{R}\right)^2 = -\frac{kc^2}{R^2} + \frac{8\pi}{3}G\varrho \tag{35}$$

$$2\frac{\ddot{R}}{R} = -\left(\frac{\dot{R}}{R}\right)^2 - \frac{kc^2}{R^2} - 8\pi Gp \tag{36}$$

read as follows (with $R = c/H$, $\dot{R} = c$ and $\ddot{R} = -Hc$):

$$H^2 = -kH^2 + \frac{8\pi}{3}G\varrho \tag{37}$$

$$-2H^2 = -H^2 - kH^2 - 8\pi Gp \tag{38}$$

In the RLM the space factor k depends on the relation between the density ϱ and the radiation pressure p, however, not on the universal mass M. For $p = \varrho/3$ (radiation era) k must be 0 to fit both (37) and (38). Accordingly, for

$p = 0$ (matter dominated era) we have necessarily $k = 1$. This may indicate, that a change in space structure must have happened during the evolution of the universe. Hovever, because in the RLM the extension of the universe $\dot{R}$ occurs with the velocity of light, the photons, also moving with c, cannot maintain an internal pressure of radiation. For this reason it is more likely that the universe always had $p = 0$ and $k = 1$.

6.1 A relation between the Hubble radius R_H and the Gravitational radius R_G:

From (35) follows in respect of $H = \dot{R}/R,\ \varrho := 3M/4\pi R^3$ and $R_H := R = c/H$:

$$\frac{c}{H}(k+1) = \frac{2GM}{c^2} \tag{39}$$

For $k = 1$ and $R_G = GM/c^2$ this leads to

$$R_H = R_G \tag{40}$$

Within the RLM the identity of expansion radius R_H (Hubble radius) and gravitational radius R_G is not a coincidence. This will be pointed out in the next section.

6.2 A relation between H and q:

Differentiation of $H = \dot{R}/R$:

$$\dot{H} = \frac{\ddot{R}R - \dot{R}^2}{R^2} = \frac{\ddot{R}}{R} - H^2 = H^2\left(\frac{\ddot{R}R^2}{R\dot{R}^2} - 1\right) \tag{41}$$

With regard to $q = -\ddot{R}R/\dot{R}^2$ we have

$$\dot{H} = -H^2(q+1) \tag{42}$$

According to (12) this equation is true for the deceleration parameter

$$q = 1 \tag{43}$$

7 Gravitation, Universal Mass and "Distant Masses"

For the state $k = 1$ equation (39) can be solved to the universal mass M:

$$M = \frac{c^3}{GH} \tag{44}$$

Inserting R for c/H we obtain the so-called "Mach principle"

$$\frac{GM}{c^2 R} = 1 \tag{45}$$

as it was quantitatively formulated by Sciama (1959). This is remarkable, because it shows, that within the Retarded Light Model the Friedmann universe based on Einsteins theory of gravitation is in full concordance with the Mach principle. Eq.(44) leads to the energy equivalent of the universe

$$E = \frac{c^5}{GH} \tag{46}$$

Equations (44) and (46) represent the sum of condensed matter and radiation. From the principle of energy conservation $\dot{E} = 0$ follows

$$\frac{d}{dt}\left(\frac{c^5}{GH}\right) = 0 \tag{47}$$

With (12) and (14) we find

$$\dot{G} = -3GH \tag{48}$$

and

$$G(t) = G_0(1 + 2H_0 t)^{-3/2} \tag{49}$$

A varying gravitational "constant" was assumed by Dirac (1937, 1938) propagating his and Eddington's (1946) "large number observations" (10^{40}-relations). (The first remarks on the 10^{40}-numbers were given 1923 by Weyl.) Gravitational experiments, though, seem to have almost excluded the alteration of G stated above (Hellings et al., Damour et al.). One has to consider, however, that the values of G and M cannot be seperated in gravitational measurements (Canuto and Hsieh). Thus we have, regarding eqs. (48) and

(51) for the product MH a relative decrease of $-H$. If c is needed for determinations of G, we even have

$$\frac{GM}{c} = \frac{c^2}{H} = const. \tag{50}$$

With the deduced time variation of the universal "constants" c, G and H we can calculate the time dependence of the universal mass M_H. According to (12), (14), (44) and (48) (respectively to (47) and $E = Mc^2$) we get

$$\dot{M} = 2MH = \frac{2c^3}{G} = const. \tag{51}$$

and

$$M(t) = M_0(1 + 2H_0 t) \tag{52}$$

An increase of universal mass has been proposed at first by Dirac to explain a large number relation, later by Narlikar and Arp to obtain a "tired light" mechanism for a non-expanding universe. They showed that when a nucleus increases in mass, the wave-length of emitted photons decrease. This process occurs similarly in the RLM.
We now define the *eigen* gravitation of the universe F_G as

$$F_G := \frac{M^2}{R^2} G \tag{53}$$

where M^2 represents the self attraction of the universal matter at maximal distance, the universal radius R. With (44) and $R_H = c/H$ we obtain

$$F_G = \frac{c^4}{G} = \frac{8\pi}{\kappa} \tag{54}$$

where κ is representing Einstein's gravitational "constant" in the field equations of General Relativity. In a next step we describe the entire energy of the universe E exclusively as the work of its *eigen* gravitation.

$$E = F_G R \overset{(53)}{=} \frac{M^2 G H}{c} = Mc^2 \tag{55}$$

Solved to M, the last two terms give $M = c^3/GH$. This expression has been deduced in a different way before. Here it results from the question: How

large must a mass m be, that its intrinsic energy is totally described by its proper gravitation?

So far only the self attraction of the universe was concerned. How does the universal "background" gravitation affect a test mass m? Inserting (44) and $R = c/H$ in (2) we obtain the gravitational potential

$$\Phi = -c^2 \tag{56}$$

That means, that the entire energy of a test mass m is determined by the universal gravitational potential. In Special Relativity the famous formula $E = mc^2$ was obtained by kinematic reflections. Here it follows from the *eigen* gravitation of the universe. This demonstrates full concordance of inertia and gravity. One may also call it "identity", as will be shown with the following considerations.

On the other hand we can define an acceleration force F_a of the universal mass caused by light retardation:

$$F_a := M\dot{c} = \frac{c^3}{GH}(-Hc) = -F_G \tag{57}$$

This equation illustrates the principle of the equivalence of ponderable and inertial mass. While Einstein presumed the equivalence principle to proceed from Special to General Relativity he did not provide an explanation. Such an explanation is possible within the Retarded Light model: Let all matter of the universe be located on the $\mathcal{R}_3$-"surface" of a 4-dimensional space $\mathcal{R}_4$. As stated above, light retardation is identical with isotropic space expansion in $\mathcal{R}_4$, which causes an inertial force on all mass particles on $\mathcal{R}_3$ towards the center of $\mathcal{R}_4$. This inertial force is being registered as gravitation in the $\mathcal{R}_3$-subsphere. This can be illustrated with an analogous *gedanken* experiment reduced by one dimension: Let us imagine an air balloon in gravitation-free space, which is half-ways blown up, and let us place a metal ball somewhere on its surface. We then blow up the balloon quickly. Due to inertia the metal ball will be pressed towards the balloon surface and cause a dent. Now we repeat the experiment with two metal balls being located close to each other on the surface. Then both balls will form a common dent in which they start moving against each other just as in a gravitational field. And indeed, a 2-dimensional observer on the balloon surface $\mathcal{R}_2$ not noticing space expansion will describe the phenomenon as gravitation, maybe even as hypothetical but

imperceptible space curvature just like Einstein. Returning to the universal situation we can say that space expansion in $\mathcal{R}_4$ causes inertia, which is being percepted as gravitation in $\mathcal{R}_3$. Gravitation, on the other hand, causes energy degradation of electromagnetical processes, which can be understood as light retardation. Finally, light retardation is via gravity identical with expanding space. Because of that identity proposed by the RLM we emphasize the point that *gravitation causes expansion*, while the standard theory expects the expansion to be *delayed* by gravitation.
A historical remark: In Newtonian physics the equivalence of inert and ponderable mass was a pure coincidence. Einstein used this fact as an Equivalence Principle. Its explanation in the sense of their identity, however, is provided by the RLM.
In a further step we can write the inert mass F_a as $M\ddot{R}$ and obtain from (57) the following classical (Newtonian) differential equation for the equivalence principle:

$$M\ddot{R} + \frac{M^2 G}{R^2} = 0 \tag{58}$$

Its formal solution $R(t)$ agrees with eq.(17). With the values for M, R and $\ddot{R}$ inserted, the identity of inertia and gravity is obvious.
With the identity of $|F_a| = Hcm$ and $|F_G| = MmG/R^2 = Hcm$ the energy E_m of a test mass m on the $\mathcal{R}_4$-surface with the radius R is the product

$$E_m = \int |F_a| dR = \int |F_G| dR = \int HcmdR = mc^2 \tag{59}$$

This result completes the above considerations concerning the interaction of the universal mass with a test mass m.
These examples show the high degree of self-consistence of the Retarded-Light-Universe. It reveals to be highly "Machian". In the course of its elaboration the equivalence of gravity and inertia was generalized with the aid of the IP and further to the equivalence of expansion and gravitation (resp. gravitation and light retardation). Referring to all of these aspects we use the term "Generalized Equivalence Principle" (GEP).

8 Friedmann Variables Versus Einstein Constants - An Alternative Approach

In the last section we have found $|\phi| = c^2$. Inserting this result in Møller's expression for ε and μ we obtain time-independent electromagnetical constants. With these values the velocity of light would also be constant. Is there a contradiction to the varying c as found above?The answer could be: yes, but only insofar as one is willing to admit a contradiction between General Relativity and Friedmann's equations. With the universal expansion time, with the cosmic background radiation we have an absolute reference frame, which should not exist in the Theory of Relativity. On the other hand one can have the point of view, that quantities in the frame of GR do not necessarily have the same meaning as in the frame of a Friedmann universe. When R varies in the Friedmann model while it is constant in GR and others of its solutions, why should not other quantities like c and G can be constant in GR and *simultaneously* varying in the Friedmann universe? If one accepts this argument one can ask how the light speed in the Friedmann model c_F must vary so that Einsteins c_E can be kept constant. From equation (1) follows

$$c_E = c_0(1 + 2\Phi/c^2)^{-1/2} \tag{60}$$

The gravitational potential is given by

$$\Phi = MG/R \tag{61}$$

We find that with increasing R, which is essential in the Friedmann model, c_E can be kept constant in any case if c_F^2 varies proportionally to ϕ. We then obtain in the Friedmann units

$$\Phi = c^2 = \frac{MG}{R} \times const. \tag{62}$$

Solved to R we immediatly obtain the satisfying result

$$R(t) = MG/c^2 \times const. = R_G \tag{63}$$

Only from adjusting c_F in a way that c_E remains absolutely constant, we achieve with $const. = 1$ the identity of gravitational and expansion radius! Replacing the universal mass M by its energy we have

$$EG/c^4 = R \tag{64}$$

This is, beside the factor 8π, the contracted, direction-independent form of Einsteins gravitational equations. With $R = c/H$ we have $E = c^5/GH$ for the total energy in the universe. Since this magnitude remains constant we obtain the following differential equation:

$$5\frac{\dot{c}}{c} - \frac{\dot{H}}{H} - \frac{\dot{G}}{G} = 0 \tag{65}$$

On the other hand we see from eq. (64) that G/c^4 must vary proportionally to R. Differentiation of $G/c^4 \propto R$ gives with $GH \propto c^5$ the result

$$\frac{\dot{G}}{G} - 4\frac{\dot{c}}{c} \propto H \tag{66}$$

Inserting (65) in (66) yields

$$\dot{R} \propto c \tag{67}$$

or

$$R = c/H \propto \int c dt \tag{68}$$

Starting out from the absolute constancy of c in a varying gravitational field we obtain the same results as above. To achieve a complete solution of the two differential equations above, we still need the relative variation of one of the magnitudes c_F, G_F or H. With the considerations of sections 4 and 5 we adopt the relation $\dot{c} = -Hc$ from observation (cosmological redshift) and have the Retarded Light Model.

To avoid two values c_E and c_F one could tentatively regard c in (60) as constant. In this case $MG/R = MGH/c$ must be constant as well. The universal mass is then constant, too, because of $E/c^2 = const. = M$. With this we would obtain $G \propto R$ and $G \propto 1/H$. That yields for both an increasing universal radius R and universal time $1/H$ the very unlikely case of an increasing gravitational "constant" G. Beside this, there would arise another problem. Equation (60) is recursive, since c^{-2} can be replaced by $\varepsilon\mu$, and both again by eq. (1), and so forth. With the distinction of c_E and c_F as suggested above this recursion can be avoided.

The intention of this chapter was to demonstrate that a constant c_E in General Relativity implies a variable c_F in a Friedmann model with varying R respectively Φ. We have adjusted c_F in a way that c_E remained constant.

This led to the solution of the horizon problem. Restricting the varying constants c and G to the Friedmann model we do not have to alter the Einstein equations in the sense of Brans-Dicke-theories, since in this frame these magnitudes remain constant, as shown. The original approach was based on differing mathematical and physical units in a Friedmann universe. The alternative approach lined out in this section does not scrutinize the problem of measurement but assumes different behaviour of "constants" in Einstein and Friedmann frame, such as c_E and c_F. Both approaches yield the same results and are obviously identical.

9 Emission of Light and Temporal Relations

In a previous section we have described light propagation in the universe in terms of the conveyor belt model. We have assumed a light source with constant emission frequency ν. This was in fact a mathematical setting. As pointed out before, we do not rely on "ideal" scales like an *a priori* constant time. We rather use a physical process like the electron's change from one energetic level of the atom to another. The question is, whether the frequency changes in cosmic dimensions. If so, this would affect the theoretical explanation of the observed red shift. In the Bohr model (we use the Hydrogen atom) the emitted frequency ν from the mth to the nth level is given by

$$\nu = \frac{m_e e^4}{8\varepsilon^2 h^3}\left(\frac{1}{n^2} - \frac{1}{m^2}\right) \tag{69}$$

The Planck constant h and the electric charge e are absolute constants in this frame (for example Møller [1972], p. 416f). The dielectric parameter ε has, as mentioned above, the temporal variation

$$\varepsilon(t) = \varepsilon_0\sqrt{1 + 2H_0 t} \tag{70}$$

(The magnetic field "constant" μ has the same time dependence. Both ε and μ compute the function of $c(t)$ as given in eq. [16].) It remains the mass m_e of the electron. If it varied proportional to the universal mass M (eq. (52), then the emission frequency of electromagnetic radiation would be constant, so that the mathematical time would be identical with the physical time. However, there is evidence that the electronic mass varies slightly (see part 2, section 5).

Regarding the conveyor belt model it is obvious that the observed frequency must decrease with runtime respectively distance from the source, since a remote observer receives longer wave-lengths being emitted in earlier times, while the speed of light is identic everywhere in three-space $\mathcal{R}_3$. We determine the variation of ν in dependence of the distance from the source. Inserting (3) in (8) yields:

$$R(t)\nu(t)/c(t) = const. \tag{71}$$

According to the values for $R(t)$ and $c(t)$ we have a variation of $\nu \propto 1/(1+2H_0t)$. This result can be evaluated more precisely. According to (7) we have

$$\int_{t_0}^{t_0+\delta t_0} \frac{c(t)dt}{R(t)} - \int_{t_1}^{t_1+\delta t_1} \frac{c(t)dt}{R(t)} = 0 \tag{72}$$

Integration yields

$$ln\left(\frac{[1+2H_0(t_0+\delta t_0)](1+2H_0t)}{(1+2H_0t_0)[1+2H_0(t_1+\delta t_1)]}\right) = 0 \tag{73}$$

Because the counter must equal the denominator we obtain the relation $(1+2H_0t_0)/\delta t_0 = (1+2H_0t_1)/\delta t_1$ or, according to (6),

$$\nu_0(1+2H_0t_0) = \nu_1(1+2H_0t_1) \tag{74}$$

Setting ν_0 for $t_0 = 0$ and $\nu(t)$ for ν_1 we obtain the expression

$$\nu(t) = \frac{\nu_0}{1+2H_0t} \tag{75}$$

This equation corresponds to the situation of an observer receiving light from sources of various distances at the same time, as it is the case when looking at the nightly sky. Comparing this result with eq. (15) we see that this delay in frequency as a function of runtime (or distance) represents the Hubble flow. Looking towards the past, cosmic time seems to elapse twice as fast as on earth. (This result may play a role for the determination of the Hubble parameter.) Accordingly, the age of the universe is $1/2H_0$. This seems to be a very short time. It has to be remarked, however, that this is a mathematical time with no physical relevance. If we use a physical clock and define the unit of time being equal to one electromagnetic oscillation of a certain frequency ν,

then we obtain for the number N of oscillations, which represent the physical time elapsed between the present $t_0 = 0$ and $-1/2H_0$:

$$N = \int_{-1/2H_0}^{0} \frac{\nu_0 dt}{1 + 2H_0 t} = -\infty \tag{76}$$

This physical time may not be "equidistant" in the mathematical sense, however, it provides at least the comforting argument that the universe has physically existed "forever".

10 Density of Matter and Radiation and its Temporal Variation

The density of matter ϱ_m and the density of radiation $\varrho_r = \varrho_m c^2$ are not distinguished in standard cosmology because $c = const.$ is assumed. This leads to a temporal variation of $\dot{\varrho} = (\varrho + P/c^2)(-3\dot{R})$ with the result that $\varrho_m(t)R(t)^3 = const.$ and $\varrho_r(t)R(t)^4 = const.$ The decrease of ϱ_r with a power of 4 is explained by a redshift effect of wave-lengths in addition to the three spatial dimensions. The RLM has no expansion of wave-lengths. This fact must be clearly deduceable from the field equations of GR. They are

$$R_{\mu\nu} = -\frac{8\pi G}{c^4}\left(T_{\mu\nu} - \frac{T}{2}g_{\mu\nu}\right) \tag{77}$$

The matter distribution in the universe is described by the tensor

$$T^{\mu\nu} = \left(\varrho + \frac{P}{c^2}\right)u^\mu u^\nu - g^{\mu\nu}P \tag{78}$$

According to the Friedmann-Universe we have spatial homogeneity of density ϱ and pressure P: $\varrho(r,t) = \varrho(t)$ and $P(r,t) = P(t)$. With these constraints the 00-component of eq. (77) is

$$3\ddot{R} = -\frac{4\pi G}{c^4}(\varrho c^2 + 3P)R \tag{79}$$

The spatial components all lead to the equation

$$R\ddot{R} + 2\dot{R}^2 + 2kc = \frac{4\pi G}{c^4}(\varrho c^2 - P)R^2 \tag{80}$$

For $P = \varrho c^2/3$ both equations are identical only for $k = 0$. ($R = c/H$, (13) and (14) have been used here.) This would result in a radiation density of

$$\varrho_r = 3H^2c^2/8\pi G =: \varrho_c \tag{81}$$

As mentioned above, because of (13) it is doubtful, whether a radiation pressure had existed in a radiation-dominated era. For $P = 0$, a scenario without remarkable radiation pressure, both equations are only identical for $k = 1$. Here the radiation equivalent of the matter density ϱ_r is

$$\varrho_r = \frac{3H^2c^2}{4\pi G} = 2\varrho_c \tag{82}$$

Equations (81) and (82) show an important result: In both cases the temporal variation $\dot{\varrho}_r$ is

$$\dot{\varrho}_r = -3H\varrho_r \tag{83}$$

Accordingly we have a temporal variation of matter density in the case $P = 0$ and of the matter equivalent of radiation pressure in the case $P = \varrho c^2/3$ of

$$\dot{\varrho}_m = -H\varrho_m \tag{84}$$

The universal density can be derived from inserting (35) in (36) with $R = c/H$, (13), and (14). This gives the so-called equation of state

$$\varrho c^2 + 3P = \frac{3H^2c^2}{4\pi G} \tag{85}$$

Assuming $P = 0$ for the whole history of the universe we always have the result of eq.(82). And indeed, Weinberg (1972) admits, that, "if we give credence to the values $q_0 \simeq 1$ and $H_0 \simeq 75$ km/sec/Mps [...], then we must conclude that the density of the universe is about $2\varrho_c$" (p. 476). In the RLM the critical density ϱ_c is just a definition and does not have the meaning of the standard model, which has a strict opposition of gravitation and expansion (and wonders why their values seem to equal each other so perfectly).
As the spatial volume V of the universe is M/ϱ, we obtain the result

$$V = \frac{4\pi R^3}{3} \tag{86}$$

This has been implicitly used for eq.(39). In standard cosmology this volume is a consequence of $k = 0$, which indicates an equilibrium between gravity and

expansion. This state of equilibrium is an integral part of the RLM, in which the meaning of k differs from the standard model. Therefore the assumption (86) is subsequently justified. The next section will provide further evidence that the Retarded Light-universe is not "closed" as k indicates.

11 On the Acceleration of Expansion

The discovery in the recent years that the luminosity of supernovae is smaller than their redshifts suggest (Perlmutter et al., Riess et al.,), has brought much confusion into cosmological research. Anything could be expected but an accelerated expanding universe. On the contrary: in the standard model expansion is expected to be delayed by the *eigen* gravitation of the universe. The cosmological constant Λ has been revived, models of antigravitation and even of a ominous "quintessence" (tracker field) have been suggested (Turner, Wang et al., Picon et al, Caldwell et al., Ostriker and Steinhardt). The RLM, however, predicts an acceleration.

First, it will be demonstrated that in the RLM a measured redshift z results in a larger distance D as in the standard model. This will explain the weaker luminosity observed at far supernovae. Then a mathematical indication for an accelerating universe will be given. As mentioned above, eq.(1) is valid in the standard model as well as in the RLM. This implies

$$R(t_1)\nu_1 = R(t_0)\nu_0 \tag{87}$$

where ν_1 is the at time t_1 emitted and ν_0 is the received frequency at time t_0. In the standard model with constant c the frequency can be replaced by the wave-length as follows: $R(t_1)\lambda_0 = R(t_0)\lambda_1$. The spectral redshift z is defined

$$z = \frac{\lambda_0 - \lambda_1}{\lambda_1} = \frac{\lambda_0}{\lambda_1} - 1 = \frac{R(t_0)}{R(t_1)} - 1 \simeq \frac{H}{c} D_{Standard} + \dots \tag{88}$$

(The restriction to the linear term of distance D does not alter the result in the sense of argumentation.) The RLM has at the point of emission:

$$\nu = \frac{c(t)}{\lambda(t)} = const. \tag{89}$$

Insertion of (89) in (87) yields

$$\frac{R(t_1)c_1}{\lambda_1} = \frac{R(t_0)c_0}{\lambda_0} \tag{90}$$

This leads to an altered determination of z in the RLM:

$$z = \frac{R(t_0)}{R(t_1)} - 1 = \frac{\lambda_0 c_1}{\lambda_1 c_0} - 1 = \frac{H}{c_0} D_{RLM} + \ldots \tag{91}$$

Since c decreases, the speed of light at emission time is always higher than at reception, thus we have $c_1 > c_0$. Comparing (91) with (88) we have

$$D_{RLM} > D_{Standard} \tag{92}$$

In words: For the same measured redshift z the RLM yields a larger distance D to cosmic objects like supernovae as the standard model. This important result explains the observed lack in luminosity.
The acceleration of expansion is kind of a natural process within the RLM without need of any external forces. Because the deceleration of c the universal mass M must increase for $E_{univ} = Mc^2 = const$. In (51) and (52) the values of this process are given. Increasing mass of and in the universe means more gravitational delay of photons; they will slow down even more. The growing deceleration rate, however, is equivalent to a more and more accelerating universe, according to the GEP. The latest determinations of redshift and luminosity of supernovae can be understood as a confirmation of the Generalized Equivalence Principle of expansion, light retardation, and gravitation.
One more remark on extension, expansion, and accelerated expansion: The extension of the universe is given by $\dot{R} = c$ (see eq.13). Its expansion is determined by the rate of light deceleration $\ddot{R} = \dot{c} = -Hc$ (see eq.14). We obtain the acceleration rate of expansion by differentiation of $\dot{c}$,

$$\ddot{c} = 3H^2 c \tag{93}$$

12 Problems of the Standard Model: Horizon, Flatness, Density Fluctuation

One of the classical problems of the standard model is the incompatibility of the event radius (extension) with expansion. The event radius $\mathcal{D}$ is given

by $\mathcal{D}(t) = ct$, constant c provided. Thus the causal event horizon has a time dependence of $\mathcal{D} = const. \times t$. The time dependence of expansion, derived from Friedmann's equations is $R(t) = const. \times t^{2/3}$. That means, that different parts of the universe must have been less causally connected in the past – a contradiction to the demand of a homogeneous universe, which produced just those equations found by Friedmann.
In the RLM, both radii have the same temporal development. For $\mathcal{D}$ we have

$$\begin{aligned} \mathcal{D}(t) &= \int c(t)dt = \int \frac{c_0 dt}{\sqrt{1+2H_0 t}} \\ &= \frac{c_0}{H_0}\sqrt{1+2H_0 t} = R_0\sqrt{1+2H_0 t} = R(t) \end{aligned} \tag{94}$$

In particular we have from the origin of the universe ($t = -1/2H_0$) up to the presence ($t = 0$)

$$\mathcal{D}_0 = \int_{-1/H_0}^{0} \frac{c_0 dt}{\sqrt{1+2H_0 t}} = \frac{c_0}{H_0} = R_0 \tag{95}$$

The identity of both horizons in the RLM is impressively confirmed; their time dependence is $\mathcal{D}(t) = R(t) = const. \times t^{1/2}$. To verify this result we insert eq.(13), the functions of $c(t)$ (see eq.16), $G(t)$ (see eq.49) and

$$\varrho_m(t) = \frac{\varrho_{m0}}{\sqrt{1+2H_0 t}} \tag{96}$$

which follows from (84), in Friedmann's first equation (35).

$$\dot{R}^2 = -kc^2 + \frac{8}{3}\pi G \varrho_m R^2 \tag{97}$$

Solved to R and all of the above functions inserted yield

$$R = \sqrt{\frac{3(1+k)c_0^2(1+2H_0 t)}{8\pi G_0 \varrho_{m0}}} = const. \times t^{1/2} \tag{98}$$

These calculations show that there is no horizon problem within the frame of the RLM.

The Retarded Light Model also provides an explanation for the present flatness of the universe. Dividing (35) by H^2 and setting $\varrho_c = 3H^2/8\pi G$ we obtain the following equation for the curvature of the universe:

$$\frac{k}{R^2} = \frac{H^2}{c^2} \times \frac{\varrho(t) - \varrho_c}{\varrho(t)} \tag{99}$$

(ϱ means the density of matter.) Multiplication of both sides with ϱ_c/ϱ yields:

$$\frac{\varrho - \varrho_c}{\varrho} = \frac{3kc^2}{8\pi G\varrho R(t)^2} = const. \tag{100}$$

This is valid for a matter dominated as well as for a radiation universe. The constancy in (100) is a consequence of the known functions of time c, G, ϱ, and R. Thus we get for the curvature after inserting the proportionality term of (100) into (99):

$$\frac{k}{R^2} \propto \frac{H^2}{c^2} \times const. = R(t)^{-2} \times const. \tag{101}$$

This result indicates that the curvature of the universe is proportional to $R(t)^{-2}$. Possible fluctuations around $\Omega = \varrho/\varrho_c = 1$ do not enlarge as in the standard model but remain in the same relation. And another remark: Since we know that in the RLM $k = 1$, we can replace the proportionality symbol by equality in (101). Everything in the RLM fits perfectly, whereas the standard model produces sometimes – as in this case – weird results. To compensate the missing (or very small) space curvature observed today the standard model had to introduce the *ad hoc* process of an inflationary universe, reviving the cosmological constant, which causes even more trouble than it prevents (Abbott 1988).
Along these lines the remaining cosmological problems of the standard model, such as the increasing density fluctuation during expansion, can be solved.

13 The Temperature of the Universe

Since in the presented model electromagnetic waves do not scale with $R(t)$, the relation between the scale factor or radius of the universe and its temperature T should differ from the standard model. However, here arises a

problem, which concerns the standard model just as well as the RLM. The question is, from which spectral distribution the temperature of the universe shall be determined. If the universe is regarded as a "black box", then the Planck distribution would be a good candidate. In an expanding universe, however, the Planck distribution needs a certain relation between T and R to maintain itself during expansion. This condition is

$$T(t) \propto \frac{1}{R(t)} \tag{102}$$

This sounds surprising because this relation is in the standard model frequently derived from the Stefan-Boltzmann law $\varrho_r = aT^4$ with $a = \pi^2 k^4/15\hbar^3 c^2$ and a conclusion from one of the Friedmann equations $\varrho_r \propto R^{-4}$. These two relations yield $T \propto 1/r$. However, the use of the Stefan-Boltzmann law implies the validity of the Planck distribution, whereas the Planck distribution needs the relation (102) to "survive" in an expanding universe. To break this vicious circle we must refer to experimental determinations of the cosmic background radiation (CBR), which show indeed a good approximation to a Planck distribution around 2.73 K. Because of this observational result the RLM will also rely on the relation described in (102), although the radiation density ϱ_r relates in a different way to R (see eq.83) as in the standard model. The Stefan-Boltzmann law solved to the universal temperature T(t) is

$$T(t) = \sqrt[4]{\frac{15\hbar^3 c^5 \varrho_r}{\pi^2 k^4}} \tag{103}$$

where $\hbar$ is the Planck constant divided by 2π, and k is the Boltzmann constant. Most of the "constants" under the root symbol are functions of t. Since $R \propto \sqrt{t}$ the temperature T must be proportional to $t^{-1/2}$ to satisfy (102). The time dependence of c and ϱ_r are given in (16) and (83). The latter gives

$$\varrho_r(t) = \varrho_{r0}(1 + 2H_0 t)^{-3/2} \tag{104}$$

after integration. If the Planck constant h is assumed to be constant, then the Boltzmann "constant" k must obey the temporal variation

$$k(t) = \frac{k_0}{\sqrt{1 + 2H_0 t}} \tag{105}$$

or differentiated

$$\dot{k} = -kH \tag{106}$$

With the above conditions of h and k the relation (102) between T and R holds, so that the thermal evolution of the universe can be treated analogously to the standard model. It has to be emphasized that the variation of the Boltzmann "constant" k is no additional assumption. It follows from the observation that the spectrum of CBR is distributed in a Planckian manner. As pointed out, the standard model also has to refer to that empirical fact, which is problematic in a certain way, because the assumption of a Planck distribution requires a radiation equilibrium, which should not exist in the standard model because of its horizon problems. The suggested model, however, is Mach connected and its radiation is much more in a state of equilibrium.

14 Summary

The introduction of a new mechanism of light propagation in a Friedmann universe. avoids the problems of the standard model and provides a unifying description of various empirical facts. Its probably most important feature is that light waves do not scale with $R(t)$. The expanding universe is defined as expansion relative to a constant reference wave-length λ_0. Vice versa one could speak of a deceleration of c relative to an expanding Friedmann universe. Both views are treated as mathematically and physically indiscernible. This principle of equivalence of expansion and light retardation (IP) is expressed by $Rc = const.$ The relation of these two cosmological quantities allows a classification of all the various cosmological models into four categories:

(1) $c = const.$ and $R \neq const. \Rightarrow Rc \neq const.$: These conditions represent the Big Bang cosmologies including the standard model.

(2) $c = const.$ and $R = const. \Rightarrow Rc = const.$: This describes the classical Steady State models (Bondi, Gold, Hoyle).

(3) $c \neq const.$ and $R = const. \Rightarrow Rc \neq const.$: These conditions are preferred by modern Steady State theories including various Tired Light models.

(4) $c \neq const.$ and $R \neq const. \Rightarrow Rc = const.$: This characterizes the Retarded Light Model (RLM).

Because the observed cosmological redshift is usually explained by scaling light waves, it first had to be provided another interpretation of the observed redshift. Its determined value $\dot{c} = -Hc$ has been found to be in accordance with theoretical considerations given before. Some important features of the RLM were developed, including a general condition of a universe: $M_{univ} = c^3/GH$. The universal density was found to be $2\varrho_c$, where the critical density ϱ_c is just a definition taken from the standard model but otherwise meaningless in the RLM, because it was shown, that expansion and *eigen* gravitation of the universe correspond to each other in a way that a universal mass increase would lead to a delay in light propagation which is equivalent to accelerated expansion. This mechanism is referred to as the Generalized Equivalence Principle (GEP). It is obvious that there is no need of a cosmological constant Λ in the RLM.
It was shown that the RLM avoids a variety of problems of the standard model, including the recently discovered mysterious acceleration of expansion. The RLM, based on General Relativity and the Cosmologic Principle of homogeneity and isotropy, includes Sciama's version of the Mach Principle. It combines various isolated arguments which arose from dissatisfaction with some features of the standard model (Dirac, Narlikar, Milne) and puts them in a consistent frame. There is a good chance, that the Retarded Light Model can even more.

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